CONDITIONS OF FOSSILIZATION[1]

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INTRODUCTION

In the study of a fossil the first important point to determine is its state of preservation—whether the fossil under consideration be the *original*, a *cast* of the original, or a *mold* of the original.

By not observing this precaution, errors have been made, and will continue to be made unless it be definitely understood what is meant by these terms and the conditions they represent in fossils.

SUPERFICIAL CONSIDERATION OF FOSSILS

A superficial consideration of a fossil is often apt to lead to a misinterpretation of its condition of preservation, for fossils vary in this respect. *Molds* may be taken for *casts*, and described as exhibiting the external structure of the original.

[1] This paper was largely prepared in 1898–99, under the direction of the late Professor Charles E. Beecher, when the writer was a graduate student at Yale, and was submitted for the degree of master of science. Its publication has been delayed because the writer wished to collect further data, which he has done in Europe and America. Another paper is in course of preparation, in which an attempt to formulate laws governing conditions of fossilization will be made.

The writer also wishes to take this opportunity to thank Professor S. L. Penfield, of Yale, for valuable suggestions during the preparation of the original manuscript.

We find the same organisms preserved in all manner of conditions, and only by a careful comparative study of the exterior and interior markings are misinterpretations to be avoided.

Fossils of the same species have been referred to different species, and the same genera to different genera. For example, *Michelinia clappii*, Hall,[1] was misinterpreted by Edwards and Haime, and referred to *Chonostegites clappii*[2] and also to *Emmonsia* (?) *cylindrica*,[3] and by Billings to *Haimeophyllum ordinatum*[4] and also to *Michelinia intermittens*.[5] (See Figs. 1, 2, 3, 4, 5, 6, 7.) This misinterpretation was due to the peculiar ways in which this genus occurs. At times the walls are coated with silica, and then filled in with calcite. At times only the siliceous coatings are left, which give a mold of the inner walls. Then again we find that they were filled with calcite, the walls having disappeared; and in this case we have a solid mold instead of a hollow one. At times the form is partly destroyed, leaving molds, casts, and parts of the original in the same specimen.

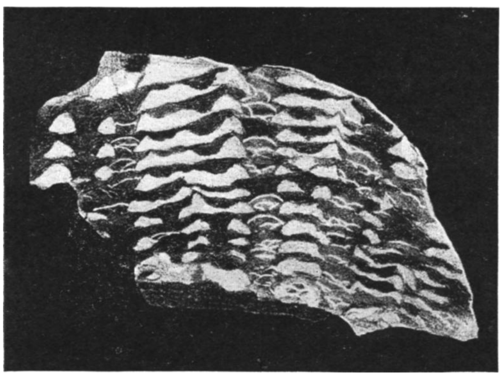

FIG. 1.—*Chonostegites clappi.* (After Edwards and Haime.)

We find fossils of the same species preserved (*a*) in their original condition, (*b*) as casts, and (*c*) as molds. In regard to the first condition little difficulty will present itself. The second and third, however, may lead to confusion, for they may not exhibit the external form.

[1] Hall, *Geology of the State of New York* (1876), "Illustrations of Devonian Fossils," Plate XVII.

[2] Edwards and Haime, Pal. Fos. d. Ten. Pal. (1851), p. 299, Plate XIV, Figs. 4, 4*a*.

[3] *Ibid.*

[4] Billings, Can. Jour. U. S., Vol. IV (1859), p. 139.

[5] *Ibid.*, p. 113.

CONDITIONS IN WHICH FOSSILS OCCUR

The following illustrations will show the various conditions in which fossils are found, and they will also serve to show the necessity for close observation and comparative study.

A. The original skeleton may be preserved. If there be hollows or spaces, they may become filled with infiltrating material. In a case of this kind little difficulty will present itself in the determination of the fossil.

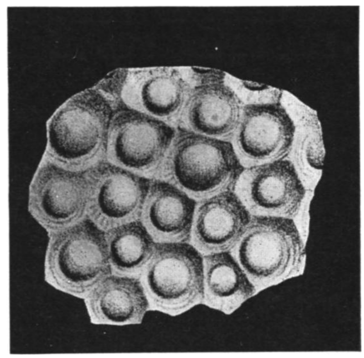

FIG. 2.—*Chonostegites clappi.* (After Edwards and Haime.)

B. The original skeleton may be replaced by some mineral and the cavities filled with the same, or some other material.

If the skeleton were composed of aragonite, and were replaced by calcite, the external form and markings would be preserved; but the internal organic structure would be lost, and hence not seen under the microscope. In this case we should depend upon external markings for identification.

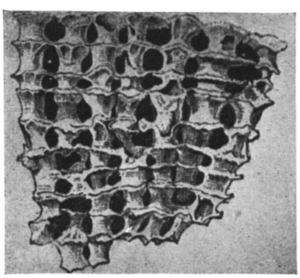

FIG. 3.—*Chonostegites clappi.* (After Miller.)

If a skeleton composed of calcite were replaced by pyrite, we could not ascertain in thin section whether the internal organic structure were lost or preserved, because of the opaqueness of the pyrite, and again we should depend upon external markings. A broken section, however, will show on the fractured surface the minutest details, in many cases.

If the organism were replaced molecularly by a mineral which transmits light, the internal organic structure would be so well preserved as to be readily distinguished under the microscope. In a case of this kind we should have a double check—the internal as well as the external structure—and its identification would be doubly sure.

C. The organism may disappear after its cavities or hollows were filled by infiltrating material. In this case we should have only the impression of the interior of the original, and it would be necessary to compare this with the interior of skeletons already known. This is at times difficult; but it is the only alternative. To make this comparison it might be necessary to take an impression, or *cast*, from the *exterior* of this filling, which cast would show the markings of the *interior* of the original. Unless we could find a fossil or a living form showing the same, or nearly the same, internal markings, we should be baffled in any attempt to adjust it to its zoölogical position, and hence its identification would remain unsolved until one of these two conditions was satisfied.

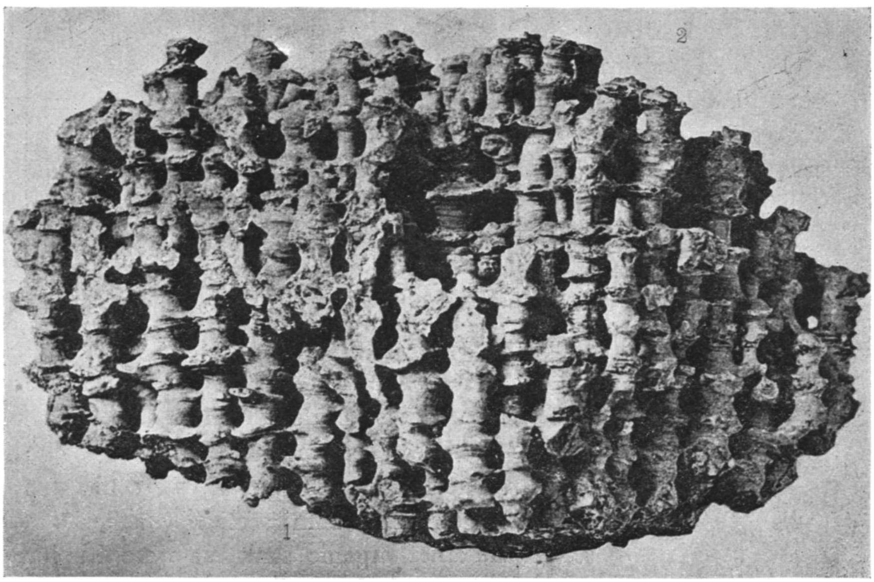

FIG. 4.—*Michelinia clappi*. (After Hall.)

D. The hard parts of an organism may leave only an impression of its exterior in the matrix. It will then be necessary to take an impression, or *cast*, from this first impression, or *mold*, and upon the markings shown on this cast will depend the identification of the fossil.

E. The exterior of the skeleton may become coated with some mineral such as silica, after which the skeleton may disappear. In this case we should have a hollow mold. It would then be necessary to take an impression, or cast, from this mold in order to ascertain the external markings of the original, and by comparing this cast with known forms we can determine its identity. At times the corallites in a compound coral will become coated with silica, and the spaces between the corallites filled with calcareous material

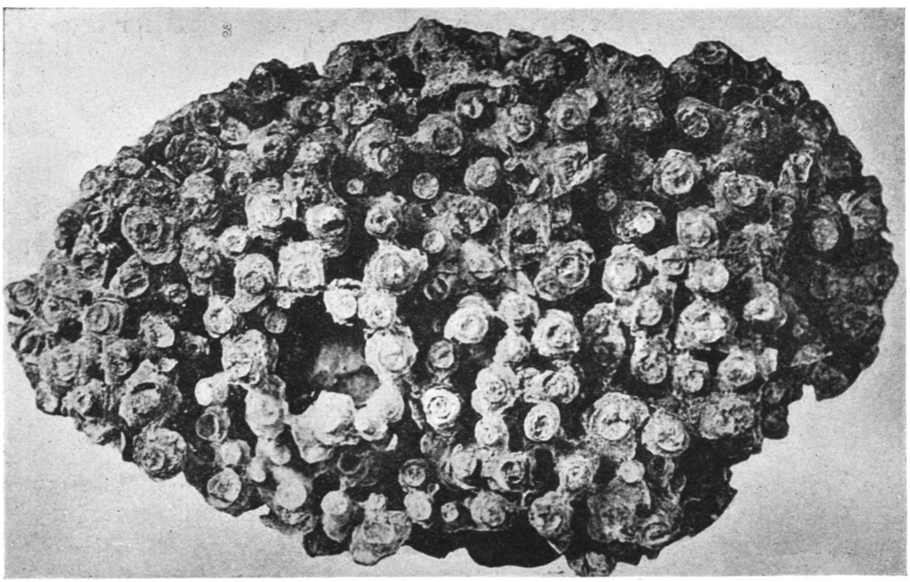

FIG. 5.—*Michelinia clappi.* (After Hall.)

the entire corallum having disappeared, leaving a mass filled with these hollow siliceous tubes, the inner surfaces of which will be molds of the exteriors of the corallites. (See *Michelinia*, previously referred to.)

We may have the exterior coated with silica, the skeleton then disappearing, and the space left filled with calcite. In a case of this kind we have molds of the exterior, and it is impossible to identify the fossil without first dissolving out the calcite, after which the procedure will be as already described.

The interior cavities or hollows of a coral may become coated with silica, after which the skeleton may disappear, leaving molds of the *interior* which will have the appearance of a sponge. If we had a coating which had been deposited upon the inner surface of the shell, it might be easily determined by taking a cast for comparison with other shells; but in the former case its identification would be extremely difficult, for we might not be able to secure casts from these molds. Even if this could be done, we might still have difficulty in its identification, for we should have only casts of the interior of the cavities or hollows of the original for comparison.

DIFFICULTIES ENCOUNTERED

From the foregoing it is plain that difficulties present themselves even when it is known that the fossil in hand is the *original*, a *mold*, or a *cast;* but the difficulties increase if it be not known what the condition of preservation is. Cases present themselves in which it is a very difficult matter to decide whether the fossil is a cast or a mold; but in the majority of cases this difficulty is obviated by close observation and an understanding of the meaning of *casts* and *molds*.

It is only by a study of casts and molds in their various conditions—found as fossils or made in the laboratory—that we may with a certain degree of exactness determine the condition of preservation of a fossil. The internal markings of some forms resemble the external markings of other forms, and it is only in the above way that we may be certain that we are dealing with external or internal markings.

There is a wide difference between a cast and a mold. Ca ts vary in that some do and some do not show the structure of the organism. *Receptaculites oweni*, Hall, from the Galena (Lower Silurian) at McGregor, Iowa, represents the inner surface of the skeleton, and is a cast. (See Figs. 1 and 8.) "In most specimens . . . . the remains consist of the filling of the intermural space, with casts of the outer surface of the inner wall, the inner surface of the outer wall, and of the connecting tubes."[1] This is a calcite

[1] Bernard, *Principles of Paleontology*, Fourteenth Annual Report, New York Geology (1895), pp. 89, 90.

cast of the interior, and has been regarded as having the structure of the original organism. The conditions were evidently such as to preclude its preservation in its original condition, or in such a condition as to render its determination certain.

AUTHORS' DEFINITIONS OF MOLDS AND CASTS

Authors differ in their definitions of molds and casts. Some make the terms synonymous. Others define them separately, but are not consistent in their application.

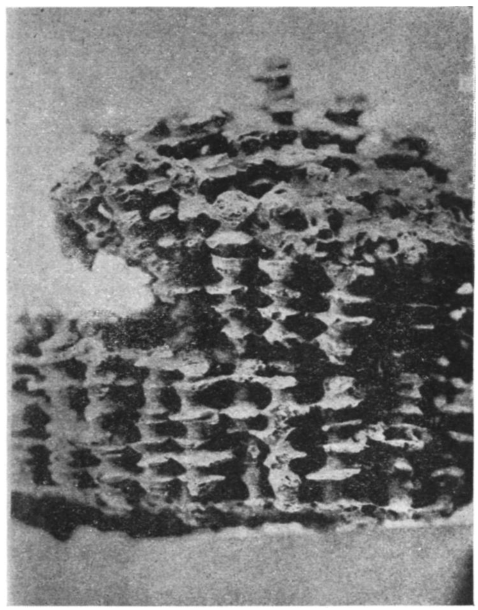

FIG. 6.—*Michelinia clappi*. (After Rominger.)

Darwin[1] considers the *mold* as a matrix, and the impression made by an organism in this matrix he terms a "cast."

Bernard[2] applies the term "mold" to three distinct results: (*a*) to an impression made by the exterior or the interior of a shell; (*b*) to molecularly replaced organisms; and (*c*) to fillings of impressions.

Gratacap[3] applies the term "cast" to (*a*) fillings which take the place of organisms, to (*b*) the material filling the space occupied by the soft parts. The term "mould" he applies to impressions of the exterior of an organism.

White[4] applies the term "mold" to impressions made by the organism. To the material filling this "mold" he applies the

[1] Darwin, *Geological Observations*, Vol. II, p. 414.

[2] Bernard, *op. cit.*

[3] Gratacap, "Fossils and Fossilization, *American Naturalist*, Vols. XXX, XXXI, pp. 288, 902, 903.

[4] White, Con. of Pres. of Inver. Fos., Bull. U. S. G. & G. S., Vol. V, No. 1, p. 135.

term "cast." He[1] also uses the term "histometabasis" for the condition which produces a molecular replacement or substitution or paramorphism.[2] He uses the term "fossil pseudomorphs" for the materials occupying cavities formerly occupied by shells, the occupation having taken place by precipitation due to infiltration. He uses the term "fossil molds" for "cavities in sedimentary rocks which were originally occupied by fossils," and says that "the original surface features and markings are often minutely preserved in molds." He also uses the term "casts" for "counter-parts of fossils," and also for the material which may occupy the animal chamber. He further speaks of making "artificial casts of natural molds" in order to get "the original form and surface features."

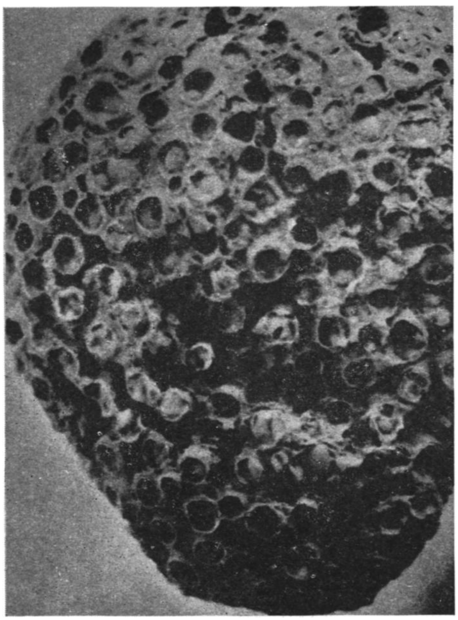

FIG. 7.—*Michelinia clappi.* (After Rominger.)

Geikie[3] applies the term "mold" to impressions made by the organism. To the material filling this "mold" he applies the term "cast." He[4] also applies the term "cast" to the material occupying the animal chamber.

Von Zittel[5] applies the term "mold" to impressions. The term "cast" he applies to the material which occupies the "interior of a shell or hollow body."

1 White, "Relation of Biological and Geological Investigations, *Proceedings of the* U. S. *N. M.*, Vol. XV, pp. 264–67.

2 Dana, *Text-Book of Mineralogy,* (1898), p. 293.

3 Geikie, *Text-Book of Geology,* 3d ed., p. 651.

4 Geikie, *Outlines of Field-Geology,* 5th ed., p. 78, Fig. 14.

5 Von Zittel, *Text-Book of Palaeontology,* Eastman translation, Vol. I, Part 1, p. 2.

Woods[1] applies the term "mold" to (*a*) the impression, to (*b*) the material filling the space occupied by the animal. The term "cast" he applies to (*a*) the material filling the space occupied by the organism, and to (*b*) the material filling the internal cavity or cavities.

Nicholson and Lydekker[2] use the terms "mold" and "cast" interchangeably.

Lyell[3] applies the term "mold" to the matrix in which an impression of the exterior has been made. The term "cast" he applies

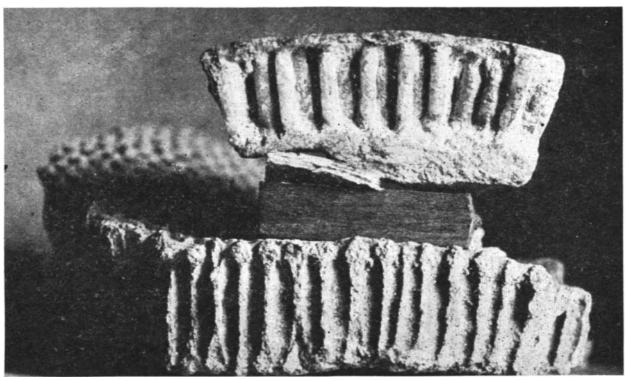

FIG. 8.—*Receptaculites oweni*, Hall. (From specimens in Yale Museum.)

to (*a*) the material filling the interior of the organism, and to (*b*) the material filling the space left by the organism.

Penning[4] uses the term "unchanged fossils" for unaltered shells or valves, or those which have lost only the animal matter. "Replaced fossils" he applies to the material which has been substituted for original material of the shell. "Internal cast" he uses for "the impression or *reversed facsimile of the external form of the organism*[5] that once filled the empty space" of the shell. The term "external cast" he uses for impressions made by the exterior of the shell, and says that "by taking an artificial cast from the

1 Woods, *Palaeontology*, 2d ed., pp. 6, 7.

2 Nicholson and Lydekker, *Manual of Palaeontology*, 3d ed., Vol. I, pp. 5, 6.

3 Lyell, *Students' Elements of Geology*, 3d ed., pp. 42–46.

4 Penning, *Text-Book of Field-Geology*, 2d ed., pp. 208–12, and Fig. 29, p. 211.

5 The writer's italics.

external impression" we obtain "an accurate representation of the pre-existing shell."

Williams[1] is perplexing in his use of the terms "mold" and "cast." He says:

> Thus a fossil . . . . may consist of the shell now removed, in which case it may be the reverse or cavity over the exterior of the shell, or . . . . similar impressions of the inner surface; or the cavity may be again filled with detrital matter, forming a cast of either the inner or outer form of the shell or object fossilized; in the former case it would be called a mold; in the latter, a cast.

Schuchert[2] applies the term "mold" to impressions of the exterior and speaks of the mold as "preserving the exterior form and ornamentation" of the shell. He is ambiguous in his use of the term "cast" for he may be referring to a matrix which contains concave impressions (impressions of the exterior of a valve) or convex impressions (impressions of the interior of a valve), or to the material which replaces a valve.

DEFINITIONS OF "MOLDS" AND "CASTS" FOLLOWED

The definitions followed in this paper are the following: A *mold* is "a form or model pattern of a particular shape, used in determining the shape of something in a molten, plastic, or otherwise yielding, state." "In founding, a *mold* is the form into which a fused metal is run to obtain a *cast.*"[3]

The *mold* determines the shape of the material put in or upon it, and this material, when removed, will be an exact duplicate of the object from which the mold was made. This removable material is termed a *cast.* The depressions in the original object will appear as protuberances in the mold, and the protuberances as depressions. The cast will show the depressions and protuberances as they appear in the original.

The surface of the original object upon or around which the mold is made may be either convex or concave. If it be concave, the mold will be convex, and *vice versa.* A mold with a convex surface is called by some authors a "cast." If the skeletal part

[1] Williams, *Geological Biology* (1895), p. 79.

[2] Schuchert, "Directions for Collecting Fossils," Part k, *Bulletin No.* 39, U. S. N. M., p. 13.

[3] *Century Dictionary,* "Mold."

of an organism be hollow or has a concavity, this space is considered a "mold" from which a "cast" is taken. This is obviously wrong, for in this case the "mold" is the *object*, and the "cast" the *mold* from which a *cast* may be taken, and *this* cast will be a duplicate of the object.

Then, again, an impression from a convex object is termed by some a "cast." This is also obviously wrong, for the "cast" would have the markings of the object in reverse order; hence it would be a mold.

The general concavity or convexity of a surface will not determine it as a mold or a cast. Such determinations depend upon the markings of that surface.

DEFINITIONS OF "ORIGINAL," "MOLD," AND "CAST" PROPOSED.

In attempting to fix the meaning of the terms "original," "mold," and "cast," it is hoped the following definitions will prove acceptable, especially the latter two:

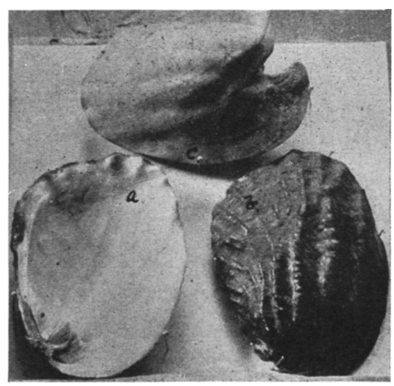

FIG. 9.—(*a* and *b*) originals; (*c*) mold of interior.

I. The term *original* is used to designate an organism[1] that has not lost its original structure or composition, to any appreciable extent, in the process of fossilization, except the organic matter which may have filled the interstitial spaces. (See Fig. 9 *a* and *b*.)

II. The term *mold* is used to designate the imprint of the exterior or interior of an organism. (*a*) If the organism leave an imprint of the exterior, this imprint is a *mold of the exterior*. (See Fig. 10.) (*b*) If the hollow organism become filled with material this material

[1] Strictly speaking, a lifeless animal is not an organism; but in common parlance the lifeless body is an organism because it is that which at one time functioned. Likewise, we speak of the products of life as organic. Therefore, for lack of a beter term, *organism* is used to denote the harder parts of animals which we term *fossils*, the softer or destructible parts of which have decayed and passed away. The term "organism" can in no sense, however, be applied to molds and casts, although these are fossils as much as the unaltered skeletal parts of animals.

is a *mold of the interior*. (See Figs. 9*c*, 11, 12.) (*c*) It follows from the above that, if the hollow organism become filled with and imbedded in material of the same, or different, composition, and then disappears, we have left a mold of the exterior in the matrix and a mold of the interior in the form of a kernel. (See Figs. 9*c*, 10.)

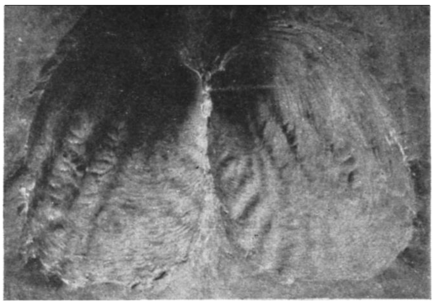

FIG. 10.—Mold of the exterior.

III. The term *cast* is used to designate the material which takes the place of the *original*, whether by replacement due to a molecular process or to infiltration. It is also used to designate the material occupying the mold made by the exterior or interior. (See Figs. 10, 12, 13, 14.)

If the mold described under II (*a*) becomes filled, we have a cast of the exterior. If the mold described under (*b*) becomes imbedded, its imprint will be a cast of the interior. If the space between the two molds described under (*c*) becomes filled, we have a cast of the exterior and interior, and therefore an object the same in shape and outline as the original. If the original be gradually replaced molecularly by some mineral, we have a cast which will show its shape, outline, and internal structure.

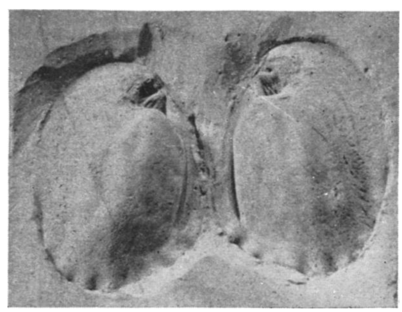

FIG. 11.—Mold of the interior.

From the foregoing it is obvious that an *original* is the organism itself; a *mold*, the reverse of the *original;* and a *cast*, the counterpart of the *original*. The latter may or may not show the internal organic structure.

It follows, therefore, that the only way one may know whether the markings on certain molds or casts represent the exterior or

interior of known forms is, as has been previously said, to make a study of molds and casts, and thus reduce the liability of mistakes to a minimum.

THE LITHOLOGICAL CHARACTER OF FORMATIONS AS AFFECTING THE PRESERVATION OF INVERTEBRATES

The conversion of an organism into a fossil depends upon the character of its skeletal parts, the material in which it is buried, and the material brought in, in solution, by infiltration. The material of which the skeletal part is composed varies in different groups, being more durable in some than in others, and therefore plays an important part in the preservation of the organism. The variation in the lithological character of the material in which the organism is buried also plays an important part in its preservation. Certain organisms are preserved as originals; others as molds and casts, in the same formation and locality. In this same formation, but in a locality of different lithological character, those groups which were lost under the former condition may be retained under the latter, and *vice versa*.

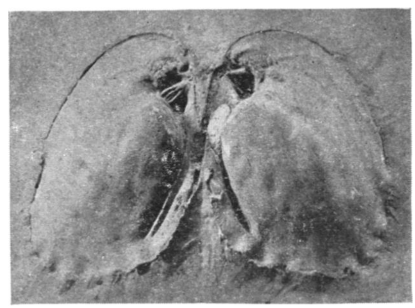

FIG. 12.—Mold of the interior.

Apparently a law could be formulated to the effect that organisms of the same mineral composition will be preserved in the same manner, as originals, molds, or casts. In reality, however, this is not true. Organisms are more completely preserved as originals in limestone; yet it is in limestone that we find the most casts by molecular replacement. Molds and casts are very common in sandstones. As limestone approaches dolomite, the molds and casts increase, although we also find originals. We find molds in hematite; but they are more rare than in sandstones.

The most perfect fossils are found in sandy and clayey shales. The Niagara group at Waldron, Ind., is made up of fine calcareous shales which are overlain by limestone. In these shales we find

quantities of corals, bryozoans, and crinoids. The brachiopods are more or less preserved as originals. The sponges, gastropods, annelids, and crustaceans are well represented. The lamellibranchs and cephalopods, however, are absent.

The Paleozoic hexactinellids occur in groups of strata containing other organisms; but in their own particular beds the absence of other forms is striking. In Steuben county, N. Y., the formation is a sandstone which is fine-grained and argillaceous, and contains very few crinoids and brachiopods; but *Hydnoceras tuberosum* occurs in abundance.[1]

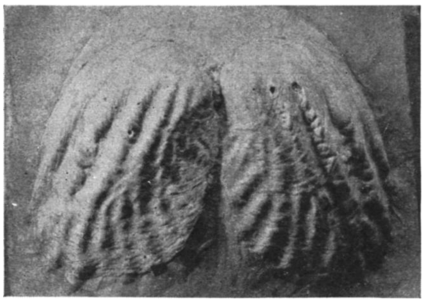

FIG. 13.—Cast of the exterior.

The fossils in the sandy and gravelly deposits of the Potsdam, the Medina, the Chemung, the Catskill, the coarse conglomerates of the Lower Carboniferous, or the calcareous grit of the Schoharie and Oriskany, all show different conditions of preservation.

The trilobites in the Potsdam of Wisconsin and Minnesota are badly broken up. In the Cambrian of Wisconsin we find argillaceous layers in which are molds and casts. The Medina sandstone contains poorly preserved fossils, and shows molds of the interior.

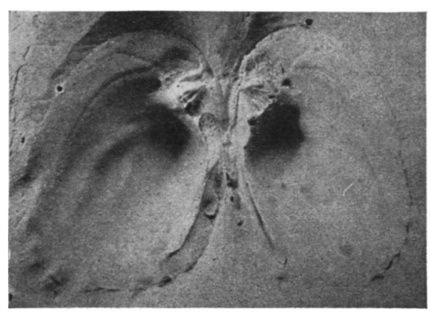

FIG. 14.—Cast of the interior.

In the calcareous sandstones of the Chemung we find well-preserved organisms; but in the Catskill sandstones they are poorly preserved.

The Utica, Marcellus, and Genessee slates show well-preserved originals; but the majority of the fossils are molds.

[1] Beecher, *Memoirs of the Peabody Museum,* Yale University, Vol. II, Part 1.

The articulate Brachiopoda, the Anthozoa, and the Bryozoa of the New York Hamilton Shales are well preserved; but the Mollusca occur as molds and casts. Trilobites, inarticulate brachiopods, and ostrocods are well preserved. In the Carboniferous shales of Illinois the Mollusca are well preserved.

In the Mesozoic sandstones of the West the fossils are casts and molds generally, with the exception of the Ostrea and allied genera.

The best fossils, as a rule, are found in those limestones which contain more or less argillaceous or siliceous ingredients, as in the Waldron beds of Indiana, the Hamilton layers of New York, and the Lower Carboniferous of Crawfordsville, Ind.

The Schoharie grit, the Oriskany sandstone, and the Calciferous beds along Lake Champlain give siliceous molds on weathering.

The Upper Helderberg limestone gives molds and casts better than sandy deposits in general. At Cumberland, Md., however, the brachiopods are perfectly preserved as casts of silica in the Oriskany sandstone.

In the Galena limestone many of the fossils are preserved as casts composed of galena. The coal-measures show molds coated with pyrite. In the Clinton of Oneida County, N. Y., we find limonite casts. In the Trenton of Wisconsin and Tennessee we find casts of silica. In the Niagara limestone of western New York we find calcite casts; but on the weathered surfaces they are siliceous. In the Schoharie grit we find siliceous molds of the interior of brachiopods.

In general, calcareous skeletal parts show an unequal persistence as fossils in their original condition. Chitinous skeletons are never preserved in their original condition.

GENERAL CHARACTER OF INVERTEBRATE SKELETONS

Chitin is confined to the Arthropoda and a few brachiopods which are made up of alternating layers of phosphate of lime and chitinous material, as in *Lingula anatina* and in the graptolites.

Silica is confined to the arenaceous Foraminifera, the Radiolaria, the Silicispongia, and Diatoms.

Calcareous material is confined to the porcellaneous and vitreous

TABLE I

HORIZON, LOCALITY, AND LITHOLOGICAL CHARACTER OF FORMATIONS, AND THE CONDITION OF PRESERVATION OF CLASSES, STUDIED

Horizon	Locality	Lithological Character	Class	Condition of Preservation	Remarks
Carboniferous	Yellow Cr., Ohio	Shale	Brachiopoda	O M*	M exterior and interior
Subcarboniferous	Crawfordsville, Ind.	Limestone	Spongiae	C	Pyrite
	Mazon Cr., Ill.	Limestone	Arachnide	M C	Exterior
	Burlington, Ia.	Limestone	Anthozoa	C	Silica
			Crinoidea	C	Calcite, silica
			Brachiopoda	O C	C siliceous
(Waverly)	Warren, Pa.	Sandstone	Anthozoa	C	Exterior, sandstone
			Crinoidea	M	Heads and arms, sandstone
			Ophiuroidea	M	Exterior, sandstone
			Brachiopoda	O M C	M exterior and interior, silica; exterior, sandstone; interior, sandstone, calcite. C exterior, silica
			Lamellibranchiata	O	Slightly changed
			Gastropoda	M	Exterior, sandstone
			Cephalopoda	M C	Sandstone
(Chester, top of)	Pulaski Co., Ky.	Limestone	Bryozoa	O	Slightly changed
(St. Louis Upper)	Breckenridge Co., Ky.	Limestone	Anthozoa	C	Silica
			Brachiopoda	O	Slightly changed
	Mt. Vernon, Rockcastle Co., Ky.	Limestone	Brachiopoda	C	Exterior, silica
			Gastropoda	C	Silica
(St. Louis)	Taylor Co., Ky.	Limestone	Anthozoa	C	Silica
			Brachiopoda	C	Silica
	Scaffold Cone Ridge, Madison Co., Ky.	Limestone	Anthozoa	C	Silica
			Brachiopoda	C	Silica
(Keokuk)	Russellville, Ky.	Limestone	Blastoidea	C	Silica
	Kings Mt., Lincoln Co., Ky.	Limestone	Anthozoa	O	Spaces filled with calcite
	Keokuk, Ia.	Shale	Anthozoa	O	Spaces filled with calcite
			Crinoidea	C	Silica
					Calcite
			Bryozoa	M C	Calcite
			Brachiopoda	C	Exterior, silica, calcite
			Gastropoda	C	Calcite
			Trilobita	C	Exterior, calcite
(Burlington, Upper)	Burlington, Ia.	Shale	Crinoidea	C	Calcite
Devonian, Upper (Genesee)	Livingston Co., N. Y.	Slate	Brachiopoda	O C	O slightly carbonized; C exterior, pyrite
			Pteropoda	C	Slate
(Chemung)	Cohocton, N. Y.	Sandstone	Spongiae	M C	M exterior, argillaceous sand; C sandstone
		Shale	Anthozoa	O	Slightly changed
	Loan Valley, N. Y.		Crinoidea	C	Calcite
			Brachiopoda	O	Slightly changed
Devonian, Middle (Hamilton)	Widder, Can.	Shale	Anthozoa	O	Spaces filled with calcite
			Brachiopoda	O	Spiralia pyrite; in some cases absent; shell filled with calcite and at times with mud
	Geneseo, N. Y.	Shale	Anthoza	C	Calcite; spaces filled with same

*O—original; M—mold; C—cast.

TABLE I.—*Continued*

Horizon	Locality	Lithological Character	Class	Condition of Preservation	Remarks
Devonian, Middle (Hamilton) —*Continued*			Crinoidea	C	Exterior, calcareous
			Bryozoa	C	Calcite
			Brachiopoda	O M C	M and C calcite
			Lamellibranchiata	O C	C exterior
			Gastropoda	C	Exterior and interior in mud; of original in mud
			Cephalopoda	C	Calcite; spaces filled with same
			Trilobita	M C	Exterior
	Pratts Falls, N. Y.	Shale	Brachiopoda	O M C	M in shale; C calcite
			Gastropoda	C	Calcite
			Cephalopoda	C	Calcite
	E. Bethany, N. Y.	Shale	Anthozoa	C	Calcite
			Brachiopoda	O	Slightly changed
			Gastropoda	O M	O slightly changed; M of exterior
	Michigan	Limestone	Hydrozoa	C	Replacement; spaces filled with calcite
	Thunder Bay, Mich.	Limestone	Anthozoa	M C	Both siliceous; C calcite
			Hydrozoa	M C	M siliceous; C calcite
			Crinoidea	C	Siliceous
			Bryozoa	M C	M siliceous; C calcite
			Brachiopoda	O M C	O slightly changed; C siliceous and calcite; M exterior and interior
			Cephalopoda	C	Siliceous
Devonian, Lower (Corniferous)	Columbus, Ohio	Limestone	Anthozoa	C	Calcite and spaces filled with same; silica, and spaces filled with same; also partly calcite and silica; calcite in matrix, but weather out silica
			Brachiopoda	O M C	M and C calcite; M exterior, silica, and also calcite
			Gastropoda	M	Interior, calcite
			Cephalopoda	C	Calcite
			Trilobita	M	Exterior, silica
	Jeffersonville, Ind.	Limestone	Anthozoa	C	Calcite
			Crinoidea	C	Calcite
			Bryozoa	C	Calcareous
			Brachiopoda	C	Calcite, also calcareous
	Charleston, Ind.	Limestone	Anthozoa	C	Calcite; Silica
			Crinoidea	C	Siliceous
			Brachiopoda	C	Siliceous
Silurian, Upper (Lower Helderberg)	Albany Co., N. Y.	Limestone (Shaley)	Anthozoa	C	Silica
			Bryozoa	C	Silica
			Brachiopoda	C	Silica
			Ostrocoda	C	Silica
			Trilobita	C	Silica
		Limestone	Trilobita	O M C	O slightly changed; M interior calcareous, exterior limestone; exterior and interior limestone; also clay; C exterior silica; interior silica
		Waterlime Limestone	Anthozoa	C	Silica
			Brachiopoda	O M C	O slightly changed; M exterior silica; C carbonized
			Pteropoda	C	Exterior, limestone
			Merostomata	M C	M exterior; shields and segments of abdomen; C carbonized
	Albany, N. Y.	Siliceous Limestone	Anthozoa	C	Siliceous
			Bryozoa	C	Siliceous
			Brachiopoda	C	Siliceous

TABLE I.—*Continued*

Horizon	Locality	Lithological Character	Class	Condition of Preservation	Remarks
Silurian, Upper (Lower Helderberg) —*Continued*	Jerusalem Hill, Herkimer Co., N. Y.	Waterlime Limestone	Crinoidea	O C	O slightly changed; C stems, calcite
	Cedarville, Herkimer Co., N. Y.	Limestone	Anthozoa	C	Calcite; silica
			Brachiopoda	O C	C calcareous; siliceous
			Gastropoda	C	Exterior, calcareous
			Trilobita	O	Tests of pygidium slightly changed
	Indian Ladder, Albany Co., N. Y.	Limestone	Spongiae	C	Siliceous
					Calcareous
			Anthozoa	C	Siliceous
			Crinoidea	C	Ring formed of silica and filled with calcite
			Bryozoa	C	Siliceous
			Brachiopoda	C	Siliceous
(Niagara)	Lockport, N. Y.		Anthozoa	C	Silica; calcite
			Crinoidea	C	Calcite
			Brachiopoda	O	Slightly changed
			Crustacea	O	Tests; slightly changed
	Charleston, Ind.	Siliceous Limestone	Anthozoa	C	Calcite; silica
			Crinoidea	C	Siliceous
			Brachiopoda	C	Siliceous
Silurian, Lower (Hudson River)	New York	Shale	Graptolitoidea	C	Carbonized
	Cincinnati, O.	Limestone	Anthozoa	C	Calcite
			Brachiopoda	O	Slightly changed
			Cephalopoda	C	Calcite
(Lower Hudson)	Clarksville, N. Y.	Shale	Spongiae	M C	M arenaceous; pyrite; manganese; C spicules replaced by silica and canals filled with calcite
	Franklin Co., Ky.	Shale	Spongiae	C	Spicules and walls of canals of silica; also calcite; canals filled with chert
(Trenton)	Kentucky	Limestone	Spongiae	C	Silica

Foraminifera, the Cœlenterates, except the Silicispongia, the Echinodermata, some of the Vermes, the Molluscoidea, and the Mollusca.

Chitin undergoes more or less alteration. In some cases it is replaced by calcite.

Silica secreted by organisms is dissolved with comparative ease. It is at times replaced by calcite. The siliceous sponges are very commonly replaced by calcite. If a siliceous organism be found as a siliceous fossil, the original silica has probably been either altered or replaced by silica.

Carbonate of lime is easily dissolved. It is made use of in two forms by organisms. In the form of calcite it is more durable than in the form of aragonite. This is due to the differences in compactibility, hardness, and specific gravity. Gastropods, many lamellibranchs, corals, and other organisms composed of aragonite crumble down and pass into calcite, or disappear, while many composed

of calcite may remain. In some strata the aragonite skeletons have entirely disappeared. This is most likely to occur in pervious beds. The presence of calcite forms does not necessarily imply that they were not associated with aragonite forms. The conditions of preservation also vary. In the Mesozoic clays we find cephalopods as originals, while in the Palaeozoic clays they are calcite casts. *Mytilus edulis* secretes aragonite as its inner layer and calcite as its outer layer. Fossils occur in which the inner layer is gone. Calcite replaces aragonite at times; but in such cases the internal organic structure is gone. As yet no example of aragonite replacing calcite has been reported.

Under Table I is given the horizon, locality, and lithological character of the formations studied, and also the class, conditions of preservation, and remarks in connection with certain forms found in these formations.

GENERAL MINERAL CHARACTER OF LIVING INVERTEBRATES

Foraminifera.—The vitreous and porcellanous forms are calcite. The arenaceous forms are siliceous throughout, or have a sandy-siliceous layer incrusting an interior calcareous layer. The *Gromidae* are chitinous.

Radiolaria.—Some are composed of acanthine and some of silica.

Spongiae.—The *Myxospongiae* are composed entirely of soft tissues. The *Ceratospongiae* are made up of spongin fibers. The *Silicispongiae* are made up of siliceous elements or contain siliceous spicules. The *Calcispongiae* contain calcareous spicules.

Anthozoa.—The *Madreporaria* are aragonite, and the *Alcyonaria* are calcite.

Hydrozoa.—The *Hydrocorallinae* are calcite (?) and the *Tubulariae* calcite (?) and chitin. The *Graptolitoidea* are chitin.

Echinodermata.—Calcite.

Vermes.—Calcite (?).

Bryozoa.—Calcite and aragonite (?).

Brachiopoda.—Calcite.

Lamellibranchiata.—Some are calcite, some aragonite, and some both calcite and aragonite in layers.

Scaphopoda.—Aragonite (?).

Gastropoda.—Aragonite. Some are composed of aragonite and calcite.

Cephalopoda.—Mainly aragonite. *Nautilus pompilius* has calcite for its inner layer and septum, instead of aragonite as heretofore reported.

Crustacea.—Mainly calcite.

REPLACING MINERALS

The hard parts of invertebrate organisms are composed of more or less soluble mineral matter, and are often replaced by other minerals which fill the cavities left by the hard parts. There may be molecular replacement as the original gradually disappears, or the cavity may be filled by precipitation after the original has entirely disappeared. Chemical reaction may take place, producing new minerals as the elements in the original unite with the elements in the matrix, or elements brought in due to the porosity of the imbedding material.

The imbedding material always contains minerals that are easily dissolved under such conditions as heat, pressure, and moisture, and they may be deposited separately or in combination. The predominating mineral is apt to be found forming molds or casts of the lost parts.

In calcareous shales we find calcite casts. In siliceous limestones we find siliceous casts. In ferruginous formations we find siderite, pyrite, limonite, etc., casts and molds. In galena-bearing formations we find casts composed of that sulphide. These illustrations might be extended; but they suffice to show how the character of a formation affects an original skeletal part in its preservation.

The most common replacing minerals are calcite, pyrite, silica, limonite, sphalerite, vivianite, barite, malachite, siderite, and hematite. The list of replacing minerals is quite large, thirty-five being the number. Others undoubtedly occur, and sooner or later will be added to our present list. Under Table II is given the replacing minerals found, and their symbols, Dana's system being followed in their classification.

In the paper to follow will be given a table showing the mineral composition of the more closely related living and fossil forms studied.

TABLE II

MINERALS REPLACING MINERALS SECRETED BY INVERTEBRATES[1]

CARBONATES, ANHYDROUS: Calcite ($CaCO_3$), Cerussite ($PbCO_3$), Magnesite ($MgCO_3$), Siderite ($FeCO_3$), Smithsonite ($ZnCO_3$).

CARBONATES, BASIC HYDROUS: Malachite ($CuCO_3.Cu(OH)_2$).

CHLORIDES, ANHYDROUS: Cerargyrite (AgCl).

FLUORIDES, ANHYDROUS: Fluorite (CaF_2).

METALS: Copper (Cu), Silver (Ag).

NON-METALS: Sulphur (S).

OXIDES, ANHYDROUS: Cassiterite (SnO_2).

OXIDES, HYDROUS: Limonite ($2Fe_2O_3.3H_2O$), Psilomelane (H_4MnO_5 (?).

OXIDES, SESQUI: Hematite (Fe_2O_3).

PHOSPHATES, ANHYDROUS: APATITE ($(CaF)Ca_4P_3O_{12}$).

PHOSPHATES, HYDROUS; Vivianite ($Fe_3P_2O_8$).

SULPHATES, ANHYDROUS: Barite ($BaSO_4$), Celestite ($SrSO_4$), Anglesite ($PbSO_4$).

SULPHATES, HYDROUS: Gypsum ($CaSO_4.2H_2O$).

SULPHIDES, DI: Pyrite (FeS_2), Marcasite (FeS_2).

SULPHIDES, MONO: Sphalerite (ZnS), Galena (PbS), Chalcocite (Cu_2S), Cinnabar (HgS).

SILICATES, HYDROUS: Kaolinite ($H_4Al_2Si_2O_4$), Gümbelite ($SiO_2.Al_2O_3.Fe_2O_3.MgO.K_2O.Na_2O.H_2O$), Glauconite (Hydrous silicate of Fe and K), Margarite ($H_2CaCl_4Si_2O_{12}$).

SILICATES, SUB: Calamine ($H_2Zn_2SiO_5$).

SILICON, OXIDES OF: Flint (SiO_2), Silica (Sio_2), Sand (SiO_2).

REFERENCES TABLE II

BERNHARD, *Éléments de Paléontologie*, 1895.

GEIKIE, *Text-Book of Geology*, 3d ed., 1893.

GRATACAP, *American Naturalist*, Vol. XXXI, No 363.

NICHOLSON and LYDEKKER, *Manual of Paleontology*, 3d ed., Vol. I, 1889.

REIS, "Ueber Petrifikation der Muskel," *Archiv für mikroskopische Anatomie*, Vol. XLI.

TRABUCCO, *La Petrificazione*, 1887.

VON ZITTEL, *Handbuch der Paläontologie.*

WHITE, *Bulletin of the United States Geological Survey*, Vol. I, No. I, Art. 8, 1879.

———*Bulletin of the United States Geological and Geographical Survey of the Territories*, Vol. V, 1880.

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